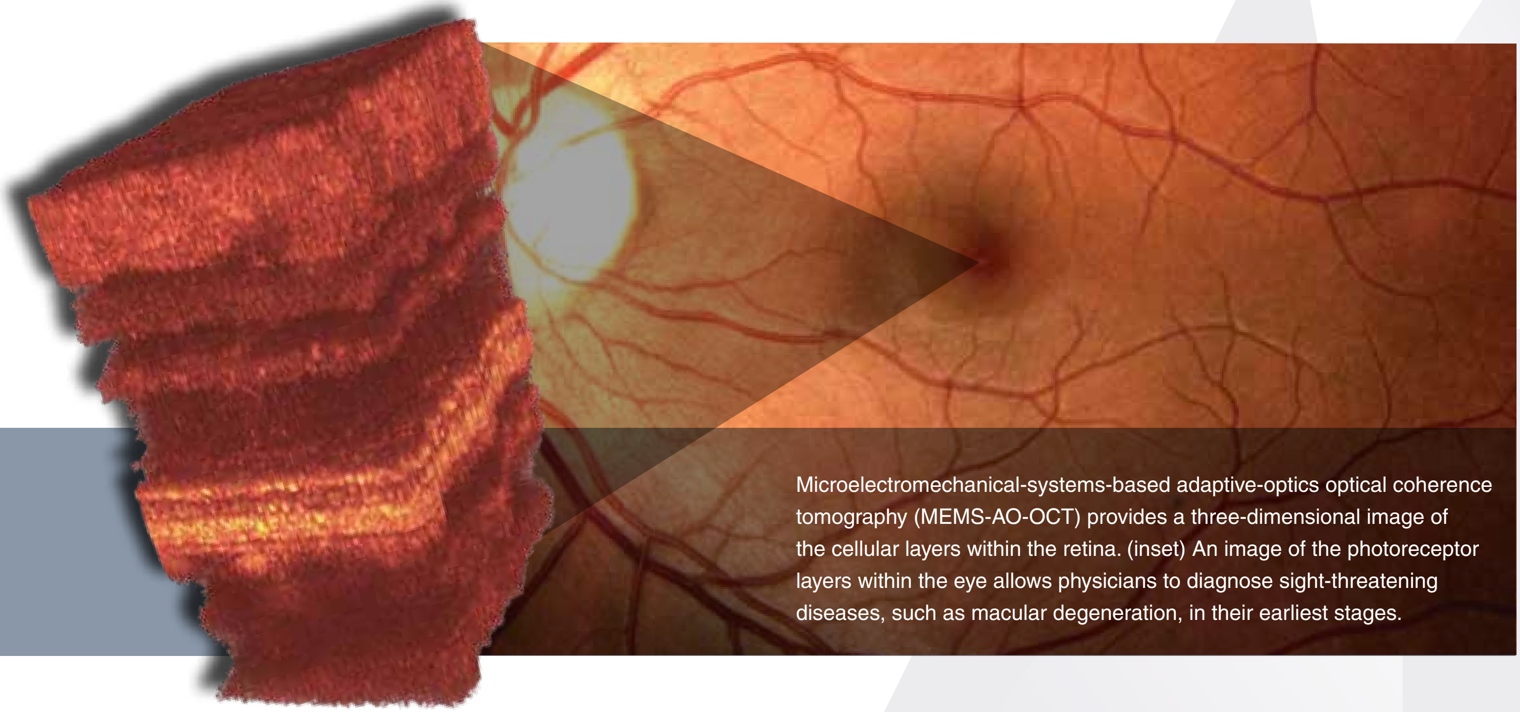

Microelectromechanical-systems-based adaptive-optics optical coherence tomography (MEMS-AO-OCT) provides a three-dimensional image of the cellular layers within the retina. (inset) An image of the photoreceptor layers within the eye allows physicians to diagnose sight-threatening diseases, such as macular degeneration, in their earliest stages.

A Look inside the Living Eye

OPHTHALMOLOGISTS and optometrists have a suite of tools for diagnosing and treating eye disease. Optical coherence tomography (OCT), for example, enables physicians to look deep inside the eye to image the subsurface tissue structure within the retina—the light-processing component of the visual system. A more advanced version of this technology has the potential to help physicians image the eye at the cellular level, allowing them to detect and monitor ocular disease at its earliest stages.

Funded by the National Eye Institute, Livermore scientists and engineers, in collaboration with the University of California at Davis, Indiana University, and Boston Micromachines Corporation in Cambridge, Massachusetts, have created an OCT system that incorporates microelectromechanical systems (MEMS) and adaptive optics (AO) to noninvasively observe and record ultrahigh-resolution, three-dimensional (3D) retinal images in real time. “Using this instrument, physicians can see the layers within a living eye in greater detail than ever before,” says Diana Chen, a Livermore engineer who is one of the lead scientists on the team. Called MEMS-AO-OCT, this device allows precise in vivo visualization and characterization of all the cellular layers in the human retina. It also provides a permanent, digitized record of clinical observations for monitoring disease progression and the effectiveness of therapeutic treatments. This year, the team received an R&D 100 Award for the breakthrough technology.

Compared with other diagnostic tools that image the internal structure of the eye, such as fundus cameras and scanning laser ophthalmoscopes, MEMS-AO-OCT is the only one that can provide 3D images of multiple layers within the retina. In addition, its automated components enable the test to be run by a technician rather than a physician, reducing a procedure’s overall cost.

Obtaining a Clear View

MEMS-AO-OCT incorporates an AO system similar to the one pioneered at Livermore, with initial support from the Laboratory Directed Research and Development Program, for use in large, high-powered telescopes, such as those at W. M. Keck Observatory on the big island of Hawaii. In this capacity, AO systems correct wavefront aberrations caused by atmospheric distortion, which blur our view from Earth of stars, galaxies, and other celestial objects. The same principle is applied to MEMS-AO-OCT, except that the optics correct and compensate for aberrations from ocular conditions such as myopia (nearsightedness), hyperopia (farsightedness), and astigmatism (irregular curvature of the lens). These conditions distort the light coming into the eye, causing blurred vision and also limiting the image resolution of retinal scans.

OCT systems are based on interferometry, where light from a single source is split into a sample and a reference beam.

These two separate beams travel along different paths until they ultimately reunite in a detector that measures their interference. In MEMS-AO-OCT, an ultrabroadband light is generated using a superluminescent diode, and the sample beam propagates through a series of telescopes, mirrors, and horizontal and vertical scanners before reaching the patient's eye. The light beam is focused onto the patient's retina in a raster, or uniform, pattern, creating individual "snapshots" of each layer. A wavefront sensor automatically measures the patient's optical aberrations. A MEMS deformable mirror working in conjunction with a Badal optometer and a pair of rotating cylinders then compensates for these distortions. "These components enable the device to be effective even for patients who have large refractive errors, obviating the need to fit patients with trial lenses," says Chen. The light reflected off the retina is then relayed back through the system to the detector. The reference beam, whose path length matches that of the sample beam, reflects off a pair of mirrors into the detector.

Compact afocal telescopes align the system components with the patient's pupil to achieve precise measurements. Inside the detector, a spectrometer and a charge-coupled-device camera record the sample and reference signatures. Custom computer software interprets the recorded signals and produces high-resolution, 3D, digital images. The device has a total footprint of approximately 0.5 cubic meters and can be easily placed and moved within a physician's office. In addition, its commercial components make the system a financially feasible option for practices, and its cost is competitive with existing instruments that have much lower resolution.

It's All in the Details

MEMS-AO-OCT technology could be adapted for use in other medical fields. Because biological tissues absorb and reflect light differently, the intensity and wavelength of the light source must be gauged to specific tissues to optimize image resolution. MEMS-AO-OCT can be easily adjusted to accommodate these varying light parameters, making it a valuable tool for diagnosing and treating many health conditions, including cardiovascular disease. In addition, dentists could image both hard (teeth) and soft (gums) tissues, and oncologists could identify cancer cells well before they develop into tumors. "The system could ultimately help medical professionals accurately diagnose diseases, dramatically reducing the cost of medical treatment and improving the quality of life for millions of people," says Chen.

Today, MEMS-AO-OCT is proving its capabilities as a state-of-the-art retinal imaging system. Livermore's academic partners, the University of California at Davis and Indiana University, have built and currently operate MEMS-AO-OCT as part of clinical trials. More than 100 patients with healthy and diseased eyes have been tested with the system thus far. Results have been promising, illustrating the system's ability to image minute changes in the retina that would not have been detected with standard imaging techniques. "Without adaptive optics, the resolution of a clinical OCT system is insufficient for imaging individual cellular structure," says Chen. "By incorporating adaptive optics and MEMS-based systems into OCT, we've developed a clinical instrument that is reliable, affordable, and far more effective than anything else on the market."

—Caryn Meissner

Livermore development team for MEMS-AO-OCT: (from left) Diana Chen, Scot Olivier, and Steven Jones.

Key Words: adaptive optics (AO), deformable mirror, microelectromechanical systems (MEMS), ocular disease, optical coherence tomography (OCT), R&D 100 Award, retinal imaging.

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